

750 GeV Diphoton Signal from One-Family Walking Technipion

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(Dated: April 22, 2016)

The ATLAS and CMS groups have recently reported an excess at around 750 GeV with the local significance by about 3 sigma in the diphoton channel at the 13 TeV LHC. We give a possible explanation for the excess by a composite pseudo scalar (P^0) predicted in the one-family model of walking technicolor.

Very recently, an excess about 3 sigma (at local significance) has been seen at around 750 GeV in the diphoton mass distribution at the 13 TeV LHC experiments [1–4]. It may indicate the existence of a new particle beyond the standard model.

In this paper, we present a possible explanation for the diphoton excess by a composite pseudoscalar boson, a pseudo Nambu-Goldstone boson of the chiral symmetry (technipion P^0) predicted in the TeV region in the one-family walking technicolor model [5, 6], a scale-invariant version [7, 8] of the one-family technicolor model [9], which successfully accounts for the LHC Higgs with the 125 GeV mass [10–12] and the couplings [13–17].

The model includes eight flavors $N_F = 8$ of technifermions (techniquarks Q_c and technileptons L) are introduced: $Q_c \equiv (U_c, D_c)^T$ (with $c = r, g, b$ being the QCD color charge) and $L \equiv (N, E)^T$, all having the technicolor N_C of $SU(N_C)$ [9]. The chiral symmetry is enhanced from that of the standard model ($SU(2)_L \times SU(2)_R$) to $SU(8)_L \times SU(8)_R$, which is broken by the technifermion condensation $\langle \bar{F}F \rangle \neq 0$ ($F = Q, L$) down to $SU(8)_V$. One thus finds 63 composite pseudoscalar Nambu-Goldstone bosons ($\sim \bar{F}i\gamma_5 T^A F$, with T^A ($A = 1, \dots, 63$) being the $SU(8)$ generators). Among 63, three are eaten by W and Z bosons, while other 60 become composite pseudo Nambu-Goldstone bosons (technipions) acquiring mass by the interactions outside of the technicolor sector, such as the extended technicolor and the standard-model gauge interactions, which break the chiral $SU(8)_L \times SU(8)_R$ symmetry in a way to keep only three exact Nambu-Goldstone bosons massless to be absorbed into W and Z while all others are massive. The masses are actually lifted up to be on the order of $\mathcal{O}(1)\text{TeV}$ [5, 6], due to the large anomalous dimension $\gamma_m \simeq 1$ of the walking dynamics, a salient feature of the walking technicolor [7, 8].

In addition to the technipions, the walking technicolor possesses a light flavor-singlet scalar ($\sim \bar{F}F$), technidilaton, arising as a composite pseudo Nambu-Goldstone bo-

son for the spontaneous breaking of the (approximate) scale invariance [7, 8, 18]. It was shown to have mass as small as 125 GeV [10–12] due to the walking nature characterized by the conformal phase transition [19], particularly near the anti-Veneziano limit $N_C \rightarrow \infty$ with $N_C\alpha, N_F/N_C = \text{fixed}$ ($N_F/N_C \gg 1$) [11, 12], in contrast to the original technicolor of naive QCD scale up, identified as the LHC 125 GeV Higgs. Such a light flavor-singlet scalar was also observed on the lattice for the large N_F QCD with $N_F = 8$ [20–22] as a concrete model of the one-family walking technicolor as well as $N_F = 12$ [23–25]. It has been shown that the technidilaton has the coupling property consistent with the current LHC Higgs data [10, 11, 13–15].

The one-family walking technicolor predicts further rich composite spectra: besides the pseudo Nambu-Goldstone bosons (technipions and technidilaton), the model predicts vector mesons ($\sim \bar{F}\gamma_\mu T^A F$, technirhos), having the mass around a few TeV. Recently, it has been shown [26–28] that the one-family walking technirhos can account for the diboson excess at around 2 TeV reported by the ATLAS collaboration at the 8 TeV LHC [29], consistently with the electroweak precision tests as well as the direct search limits from the LHC experiments.

Thus, the one-family walking technicolor has been becoming a viable candidate not only on the field theoretical ground, but also from the phenomenological aspect tested at the LHC. In this paper, we shall give yet another evidence of the one-family walking technicolor: that is the 750 GeV, iso- and color-singlet technipion (P^0) signature in the diphoton channel. It will be shown that the P^0 -diphoton signal can explain the excess about 3 sigma recently reported from the 13 TeV LHC experiments.

The iso- and color-singlet technipion P^0 , is constructed from one-family technifermions as $\sim 1/(4\sqrt{3}) (\bar{Q}i\gamma_5 Q - 3\bar{L}i\gamma_5 L)$ [9]. As noted in Ref. [5], the P^0 couplings to the standard model particles arise from the non-Abelian anomaly of the chiral $SU(8)_L \times SU(8)_R$ gauged by the standard model charges. The coupling form can unambiguously be fixed by the Wess-Zumino-Witten construction [30, 31] in terms of the chiral Lagrangian just like the case of QCD

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N_C	3	4
$\Gamma_{\text{tot}}[\text{GeV}]$	1.2	2.1
$\text{Br}(P^0 \rightarrow gg)[\%]$	99.8	99.8
$\text{Br}(P^0 \rightarrow \gamma\gamma)[\%]$	9.7×10^{-2}	9.7×10^{-2}
$\text{Br}(P^0 \rightarrow Z\gamma)[\%]$	5.3×10^{-2}	5.3×10^{-2}
$\text{Br}(P^0 \rightarrow ZZ)[\%]$	7.3×10^{-3}	7.3×10^{-3}

TABLE I: The total width and branching fraction of the P^0 at 750 GeV in the one-family walking technicolor with $N_C = 3$ and 4.

pions [5]:

$$\begin{aligned}
S_{P^0 gg} &= -\frac{N_C}{16\sqrt{3}\pi^2} \frac{g_s^2}{F_\pi} \int_{M^4} \sum_{a=1}^8 P^0 dG^a dG^a, \\
S_{P^0 \gamma\gamma} &= \frac{N_C}{12\sqrt{3}\pi^2} \frac{e^2}{F_\pi} \int_{M^4} P^0 dA dA, \\
S_{P^0 Z\gamma} &= \frac{N_C}{6\sqrt{3}\pi^2} \frac{e^2 s_W}{c_W F_\pi} \int_{M^4} P^0 dZ dA, \\
S_{P^0 ZZ} &= \frac{N_C}{12\sqrt{3}\pi^2} \frac{e^2 s_W^2}{c_W^2 F_\pi} \int_{M^4} P^0 dZ dZ, \\
S_{P^0 WW} &= 0,
\end{aligned} \tag{1}$$

where things have been written in terms of differential forms on the Minkowski-space manifold M^4 , and e, s_W, g_s and F_π respectively denote the electromagnetic coupling, weak mixing angle ($s_W \equiv \sin \theta_W, c_W^2 \equiv 1 - s_W^2$), the QCD gauge coupling, and the technipion decay constant fixed by the electroweak scale $v_{EW} = 246$ GeV as $F_\pi = v_{EW}/\sqrt{N_D}$, with $N_D = N_F/2 = 4$ for the one-family model. Note that the P^0 - W - W coupling vanishes because of the cancellation between techni-quark and -lepton contributions [5]. The partial decay widths are computed to be

$$\begin{aligned}
\Gamma(P^0 \rightarrow gg) &= \frac{N_C^2 \alpha_s^2 G_F m_{P^0}^3}{12\sqrt{2}\pi^3}, \\
\Gamma(P^0 \rightarrow \gamma\gamma) &= \frac{N_C^2 \alpha_{em}^2 G_F m_{P^0}^3}{54\sqrt{2}\pi^3}, \\
\Gamma(P^0 \rightarrow Z\gamma) &= \frac{N_C^2 \alpha_{em}^2 G_F m_{P^0}^3 s_W^2}{27\sqrt{2}\pi^3 c_W^2} \left(1 - \frac{m_Z^2}{m_{P^0}^2}\right)^3, \\
\Gamma(P^0 \rightarrow ZZ) &= \frac{N_C^2 \alpha_{em}^2 G_F m_{P^0}^3 s_W^4}{54\sqrt{2}\pi^3 c_W^4} \left(1 - \frac{4m_Z^2}{m_{P^0}^2}\right)^{3/2}, \\
\Gamma(P^0 \rightarrow WW) &= 0,
\end{aligned} \tag{2}$$

where $\alpha_{em} \equiv e^2/(4\pi)$, $\alpha_s \equiv g_s^2/(4\pi)$ and use has been made of $1/v_{EW}^2 = \sqrt{2}G_F$ with G_F being the Fermi constant. Note that all the partial decay widths are proportional to N_C^2 , so the branching ratios are independent of the number of technicolor N_C .

Using the experimental values [32] $G_F \simeq 1.166 \times 10^{-5} \text{ GeV}^{-2}$, $\alpha_s \simeq 0.118$ (at the Z mass scale), $s_W^2 \simeq 0.22$, $m_Z \simeq 91.2$ GeV, $\alpha_{em} \simeq (128)^{-1}$ (at the Z mass

scale), one calculates the total width (Γ_{tot}) and branching ratios (Br) by setting the P^0 mass to 750 GeV and choosing N_C to be a certain number, listed as in Table I. The table shows that the P^0 is a very narrow resonance with the width of $\mathcal{O}(1\text{GeV})$, in accordance with the diphoton signal reported in Refs. [1–4], and almost perfectly couple to digluon, implying the large gluon-gluon fusion (ggF) cross section at the LHC.

Now we estimate the 750 GeV P^0 cross sections at the 13 TeV LHC produced through the ggF process to get

$\sigma_{\text{ggF}}^{13\text{TeV}}(P^0)[\text{fb}]$	$N_C = 3$	$N_C = 4$
gg	7.7×10^3	1.4×10^4
$\gamma\gamma$	7.5	13
$Z\gamma$	4.1	7.3
ZZ	5.6×10^{-1}	9.9×10^{-1}

where we have used the narrow width approximation with the parton distribution function CTEQ6L1 [33]. The table in Eq.(3) thus shows that the P^0 diphoton cross sections reach the amount enough to explain the 750 GeV diphoton excess, $\sigma \times \text{Br} \sim 5 - 10$ fb read off from Refs. [1–4].

The 750 GeV P^0 signals should be consistent with the currently available LHC limits. From Refs. [34–38] one can read off the 95% C.L. upper limits on scalar resonances with mass of 750 GeV at the 8 TeV LHC as

$$\begin{aligned}
\sigma^{8\text{TeV}} \times \text{Br}(gg)[\text{fb}] &\lesssim 5 \times 10^3, \\
\sigma^{8\text{TeV}} \times \text{Br}(\gamma\gamma)[\text{fb}] &\lesssim 2.0, \\
\sigma^{8\text{TeV}} \times \text{Br}(Z\gamma)[\text{fb}] &\lesssim 4.0, \\
\sigma^{8\text{TeV}} \times \text{Br}(ZZ)[\text{fb}] &\lesssim 12.
\end{aligned} \tag{4}$$

To these bounds, the 8 TeV cross sections of the P^0 are:

$\sigma_{\text{ggF}}^{8\text{TeV}}(P^0)[\text{fb}]$	$N_C = 3$	$N_C = 4$
gg	1.7×10^3	3.0×10^3
$\gamma\gamma$	1.6	2.9
$Z\gamma$	8.9×10^{-1}	1.6
ZZ	1.2×10^{-1}	2.2×10^{-1}

which tells us that the $N_C = 4$ case is in tension with the 8 TeV diphoton bound. Thus, one may conclude that the 750 GeV P^0 in the one-family walking technicolor with $N_C = 3$ can account most favorably for the presently observed diphoton excess.

In conclusion, the iso- and color-singlet technipion P^0 in the one-family model of walking technicolor can have the diphoton signal consistent with the 13 TeV excess recently reported from the ATLAS and CMS groups. This would be a strong hint for the one-family walking technicolor to be evident in the real world, in addition to the 2 TeV walking technirho in accord with the diboson excesses. If the P^0 is present in the diphoton channel,

then some excesses in other channels expected from the numbers listed in Eq.(3), such as in dijets, $Z\gamma$ and ZZ channels, would promisingly be seen in the near future LHC Run-II data. More detailed study on the P^0 signatures in other channels and distinct signals from other walking technipions, such as QCD-colored ones, will be pursued elsewhere.

In closing, the P^0 could couple to the standard model fermions through extended technicolor interactions, as discussed in Ref. [5], although they are formally higher loops. Among the standard model fermions, the Yukawa coupling to top quark pair would be most influential with either constructive or attractive interference with the Wess-Zumino-Witten term to give significant corrections to the branching fraction of the P^0 , including possible relaxing the 8 TeV LHC constraints. Also, Yukawa couplings might be constrained by the possible excessive flavor-changing neutral current processes. Since such Yukawa coupling forms are highly model-dependent on details of the extended technicolor model building, this

issue deserves to another publication in the future.

Acknowledgments

We thank Masaharu Tanabashi for valuable discussions and encouragements. This work was supported in part by the JSPS Grant-in-Aid for Young Scientists (B) #15K17645 (S.M.).

Note added

After having finished the paper, we noticed a paper, arXiv.1512.05334, discussing the 750 GeV diboson excess in the technicolor framework. In contrast to their “ η ”-like pseudo-scalar for $N_F = 2$, our technipion in the one-family walking technicolor has enough production cross section due to the colored technifermions (techniquarks), and has no WW coupling.

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